

SPECIFICATION

TITLE OF THE INVENTION

GAS DIFFUSION LAYER FOR FUEL CELL AND MANUFACTURING

5 METHOD OF THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention concerns a gas diffusion layer for fuel cell and a
10 manufacturing method of the same.

2. Detailed Description of the Prior Art

Fig. 6 is a dismantled cross-section view showing a basic configuration of
an element cell of a solid polymer type fuel cell which is one embodiment of the
conventional fuel cell. A cell is constructed by bonding an air electrode

15 (cathode) side catalyst layer 2 containing a noble metal (mainly platinum) and a
fuel electrode (anode) side catalyst layer 3 respectively to main faces at the
both sides of a solid polymer electrolyte film 1. An air electrode side gas

diffusion layer 4 and a fuel electrode side gas diffusion layer 5 are disposed
respectively in opposition to the air electrode side catalyst layer 2 and the fuel

20 electrode side catalyst layer 3. Thereby, an air electrode 6 and a fuel electrode
7 are configured respectively. These gas diffusion layers 4 and 5 has a function
to pass an oxidant gas and a fuel gas respectively and, at the same time, to

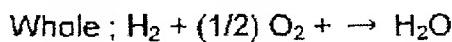
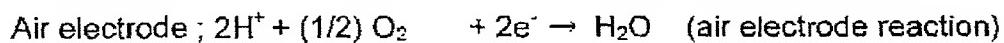
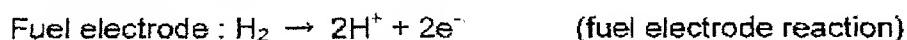
make the current flow to the outside. Then, an element cell 11 is configured by
providing a gas passage 8 for reaction gas communication facing the cell, and

25 pinching with a set of separators 10 provided with a cooling water passage 9 for
cooling water communication on the opposed main faces and formed of an
electrically conductive and gas impermeable material.

Fig. 7 is a cross-section view showing a basic composition of a solid polymer type fuel cell stack. A number of element cells 11 are stacked, sandwiched by a collector plate 12, an insulator plate 13 for of electric insulation and heat insulation, and a tightening plate 14 for maintaining the stacked state
5 by applying a load, and tightened by means of bolts 15 and nuts 17 a tightening load being applied by a plate spring 16.

The solid polymer electrolyte film 1 has a proton exchange group in the molecular, and functions as proton electrically conductive electrolyte, as the specific resistance becomes equal to or less than $20 \Omega \text{ cm}^2$, if the water content is saturated. Thus, as the solid polymer electrolyte film 1 functions as proton electrically conductive electrolyte by containing water, in the solid polymer type fuel cell, a method to operate by supplying each element cell 11 with reaction gas saturated with water vapor is adopted.
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When the fuel electrode 7 is supplied with a fuel gas containing hydrogen, and the air electrode 6 with an oxidant gas containing oxygen, the fuel sell electrode reaction for decomposing hydrogen molecular into hydrogen ions and electrons takes place in the fuel electrode 7 and the following electric chemical reaction for generating water from oxygen, hydrogen ions and electrons in the air electrode 6 respectively, the load is supplied with power by electrons moving 20 in an external circuit from the fuel electrode towards the air electrode, resulting in the production of water at the air electrode side.
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Thus, in addition to water produced by the reaction at the air electrode 6 side, water moving from the fuel electrode 7 side to the air electrode 6 side along with the movement of hydrogen ions also results in.
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Therefore, the gas diffusion layers 4 and 5 are required to assure functions of 1) supplying the catalyst layer evenly with reaction gas to be supplied, 2) conducting the current to the outside, 3) controlling satisfactorily the supply/discharge of reaction produced water and moving water, or other functions.

Consequently, in the prior art, as gas diffusion layer 4 and 5, carbon paper, carbon cloth or other electrically conductive porous material, the electrically conductive porous material subjected to the water repellent treatment, or material coated with a mixture formed of carbon powder and water repellent filler on the electrically conductive porous material have been used.

However, the conventional gas diffusion layer was expensive and, moreover, in case of carbon paper, it has been manufactured by batch as its mechanical strength is not sufficient and fragile, making difficult to form continuously in respect of the electrode manufacturing, and resulting in a poor productivity.

SUMMARY OF THE INVENTION

The first object of the present invention is to solve the problems of the prior art and to supply a cheap gas diffusion layer for fuel cell excellent in water repellency, and also excellent in mechanical strength, allowing a continuous formation.

The second object of the present invention is to provide a method for manufacturing easily such a gas diffusion layer for fuel cell.

The Inventors have studied diligently in order to solve the problems of the prior art, and as a result, found that the problems can be resolve by using a gas diffusion layer formed by using a mesh sheet having an heat resistance and an acid resistance such as, for example, stainless mesh, and filling voids of the

sheet with a mixture of electrically conductive powder such as carbon powder and water repellent filler such as fluorine resin, and devised the present invention.

- In short, the gas diffusion layer for fuel cell of claim 1 of the present
- 5 invention is a gas diffusion layer used for at least one of gas diffusion layers of a fuel cell where a fuel electrode side catalyst layer and an air electrode side catalyst layer are disposed at both faces of an electrolyte film, and further a gas diffusion layer is disposed respectively on the outer surface of the fuel electrode side catalyst layer and air electrode side catalyst layer, characterized by that :
- 10 the gas diffusion layer is formed of a mesh sheet having an heat resistance and an acid resistance, and a mixture of electrically conductive powder and water repellent filler for filling voids of the mesh sheet.

The gas diffusion layer for fuel cell of claim 2 is the gas diffusion layer for fuel cell of claim 1, wherein a second gas diffusion layer is stacked on a face of the gas diffusion layer in contact with the catalyst layer, the second gas diffusion layer being formed of the mixture of electrically conductive powder and water repellent filler, and presenting a void rate smaller than that of the gas diffusion layer.

The gas diffusion layer for fuel cell of claim 3 is the gas diffusion layer for fuel cell of claim 2, wherein the content of water repellent filler contained in the second gas diffusion layer is higher than the content of water repellent filler contained in the gas diffusion layer.

The gas diffusion layer for fuel cell of claim 4 is the diffusion layer for fuel cell of any of claims 1 to 3, wherein the fiber forming the mesh sheet is coated beforehand with water repellent material.

The gas diffusion layer for fuel cell of claim 5 is the gas diffusion layer for fuel cell of any of claims 2 to 4, wherein the thickness of the second gas

diffusion layer is smaller than that of the gas diffusion layer.

The gas diffusion layer for fuel cell of claim 6 is the gas diffusion layer for fuel cell of any of claims 2 to 5, wherein the electrically conductive powder used for the gas diffusion layer and the second gas diffusion layer is carbon powder, and the specific surface area of the carbon powder used for the gas diffusion layer is smaller than the specific surface area of the carbon powder used for the second gas diffusion layer.

The claim 7 of the present invention is a manufacturing method of the gas diffusion layer for fuel cell of claim 1 or 2, comprising the steps of; making a gas diffusion layer (precursor) using the mixture of electrically conductive powder, water repellent filler and hole making agent powder, or stacking further the second gas diffusion layer (precursor) and, thereafter, decomposing and scattering the hole making agent by heat treatment to form a gas diffusion layer having there fine holes.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 (a) is an illustrative drawing showing schematically the cross-section view of one embodiment of gas diffusion layer for fuel cell of the present invention, while (b) is a plan illustrative drawing of a mesh and porous sheet having a heat resistance.

Fig.2 (a) is an illustrative drawing showing schematically the cross-section view of another embodiment of gas diffusion layer for fuel cell of the present invention, while (b) is a plan illustrative drawing of a mesh sheet having a heat resistance and an acid resistance.

25 Fig. 3 an illustrative drawing showing the manufacturing method of one embodiment of gas diffusion layer for fuel cell of the present invention.

Fig. 4 a graphic showing the relation between cell voltage - current

density.

Fig. 5 a graphic showing the relation between cell voltage - air availability.

Fig. 6 a dismantle cross-section view showing a basic configuration of an element cell of solid polymer type fuel cell which is one embodiment of the fuel
5 cell.

Fig. 7 a cross-section view showing a basic composition of a solid polymer type fuel cell stack.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Now embodiments according to the present invention will be described in detail referring to the attached drawings.

Fig. 1 (a) is an illustrative drawing showing schematically the cross-section of first embodiment of gas diffusion layer for fuel cell of the present invention, while (b) is a plan illustrative drawing of a mesh and porous
15 sheet having a heat resistance.

In Fig. 1 (a) and (b), it should be appreciated that the same components as components shown in Fig. 6 shall be referenced with the same symbols, and their duplicate explanation shall be omitted.

As shown in Fig. 1 (a), a gas diffusion layer 4 for fuel cell of the present
20 invention is formed by filling voids 21 of a mesh sheet 20 having a heat resistance and an acid resistance as a metal mesh with a mixture 22 of electrically conductive powder such as carbon powder and water repellent filler such as fluorine. A catalyst layer 2 is formed evenly on the upper portion of the gas diffusion layer for fuel cell 4.

The material of the mesh sheet 20 having a heat resistance and an acid
25 resistance used for the present invention is not particularly limited, and for example, metals, ceramics, glass, engineering plastics or the others can be

used. As metal, to be more specific, for example, stainless steel base metals (SUS316, SUS304, or others), titan or titan alloys or others can be cited. The hole diameter of the mesh sheet 20 is also not particularly limited, but it is preferable to use those of the order of about 70 to 95% in the porosity. The

- 5 form of the mesh sheet 20 is also not particularly limited, and any of metal gauze form, plain weave form, textile cloth form, mesh form, punching metal form can be used.

The mesh sheet 20 having a high mechanical strength can play the role of cell support member. Being formed by filling voids 21 of the mesh sheet 20 with the mixture 22 of electrically conductive powder such as carbon powder and water repellent filler such as fluorine, it is excellent in gas permeability, water repellency or others, can supply the catalyst layer with reaction gas by diffusing sufficiently, and at the same time, can discharge reaction produced water or moving water satisfactorily. Moreover, an excellent mechanical strength thereof allows to form continuously easily, and to provide a cheap gas diffusion layer.

Though the mesh sheet 20 can be used as it is, it is preferable to coat beforehand the fibers of the mesh sheet 20 with water repellent material such as fluorine resin. Such preliminary coating increases the water repellency in the proximity of the fabric of the mesh sheet 20, improves and keeps the gas permeability, and at the same time, the water repellent material acts as adhesive between the fabric and the electrically conductive powder such as carbon powder, and prevents conductive powder such as carbon powder from falling from the gas diffusion layer for fuel cell 4.

25 As water repellent filler, to be more specific, for example polytetrafluoroethylene, perfluorocarbon sulfonic acid, tetrafluoroethylene-perfluoroalkylvinyl ether copolymer,

tetrafluoroethylene-hexafluoropropylene copolymer, polychlorotrifluoroethylene, polyfluorovinylidene, polyfluorovinyl, and tetrafluoroethylene-ethylene copolymer or others can be cited.

- To be more specific, as electrically conductive powder, for example,
5 carbon powder, graphite powder, carbon fiber powder, metal powder, metal fiber powder, metal plating ceramics can be cited.

Fig. 2(a) is an illustrative drawing showing schematically the cross-section of another embodiment of gas diffusion layer for fuel cell of the present invention, while (b) is a plan illustrative drawing of a mesh sheet having
10 a heat resistance and an acid resistance.

In Fig. 2 (a) and (b), it should be appreciated that the same components as components shown in Fig. 6 shall be referenced with the same symbols, and their duplicate explanation shall be omitted.

As shown in Fig. 2(a), in the gas diffusion layer 4A for fuel cell of the
15 present invention, the gas diffusion layer 4 is formed by filling voids 21 of a mesh sheet 20 having an heat resistance and an acid resistance as a metal mesh with a mixture 22 of electrically conductive powder such as carbon powder and water repellent filler such as fluorine. A second gas diffusion layer 23 is formed of a mixture of electrically conductive powder and water repellent
20 filler in the same composition ratio as the mixture 22 or in a different composition ratio thereof on a face of the gas diffusion layer 4 to be come into contact with the catalyst layer 2 of the gas diffusion layer 4. The second gas diffusion layer 23 presenting a void rate smaller than that of the gas diffusion layer 4 is stacked. The catalyst layer 2 is formed uniformly on the upper portion
25 of the second gas diffusion layer 23.

By adopting the composition, in the gas diffusion layer for fuel cell 4A of the present invention, the gas diffusion layer 4 having a mesh sheet 20 of high

mechanical strength can play the role of cell support member, while the second gas diffusion layer 23 allows to form a more uniform catalyst layer 2. Besides, since the second gas diffusion layer 23 presenting a void rate smaller than that of the gas diffusion layer 4 is disposed by stack, the second gas diffusion layer 23 can play a role to control satisfactorily the supply/discharge of reaction produced water and moving water.

Though the content of water repellent material contained in the second gas diffusion layer 23 is not particularly limited, it is preferably higher than the content of water repellent material contained in the gas diffusion layer 4.

Evaporation and scattering of reaction produced water and moving water into the reaction gas can be controlled by increasing the content of water repellent material contained in the gas diffusion layer 4.

Though the mesh sheet 20 can be used as it is, as mentioned above, it is preferable to coat beforehand the fabric of the mesh sheet 20 with a water repellent material such as fluorine resin, because such preliminary coating increases the water repellency in the proximity of the fabric of the mesh sheet 20, improves and keeps the gas permeability, and at the same time, the water repellent material acts as adhesive between the fabric and the electrically conductive powder such as carbon powder, and prevents conductive powder such as carbon powder from falling from the gas diffusion layer for fuel cell 4.

The thickness of the second gas diffusion layer 23 is not limited particularly. It is preferable that the thickness of the second gas diffusion layer 23 be inferior to the thickness of the gas diffusion layer 4. By doing this, the effect of the second gas diffusion layer 23 presenting a lower gas diffusion capacity can be limited, and the gas diffusion of the whole cell can be maintained.

The electrically conductive powder used for the gas diffusion layer 4 and

the second gas diffusion layer 4A is not specified particularly. However, carbon powder, being cheap and easily available, can be used preferably as electrically conductive powder. Moreover, it is preferable to compose so that the specific surface area of the carbon powder of the gas diffusion layer 4 be smaller than
5 the specific surface area of the carbon powder of the second gas diffusion layer 4A.

Whereby, the absorbency of the gas diffusion layer 4 becomes higher than that of the second gas diffusion layer, allowing to move excessive moisture in the second gas diffusion layer 4A and evaporate in the gas, without
10 stagnation or detention.

Fig. 3 is an illustrative drawing showing the manufacturing method of one embodiment of gas diffusion layer for fuel cell of the present invention shown in Fig. 2.

As shown in Fig. 3, first, a mesh sheet having a heat resistance and a
15 acid resistance as metal mesh is prepared, and then, treated with emulsion of water repellent material such as fluorine resin, and a water repellent treated mesh sheet is made by heat treatment.

Thereafter, a gas diffusion layer (precursor) is formed by filling voids of the water repellent treated mesh sheet with a mixture of electrically conductive
20 powder, water repellent filler and hole making agent powder. Then, the second gas diffusion layer (precursor) is formed by applying and stacking the mixture of electrically conductive powder and water repellent filler on the gas diffusion layer (precursor).

Though, in the aforementioned embodiment, the second gas diffusion
25 layer (precursor) is heat treated after stack, the second gas diffusion layer may also be formed after the heat treatment of the gas diffusion layer (precursor) before stacking the second gas diffusion layer (precursor) for obtaining a gas

diffusion layer by decomposing, scattering and removing the hole making agent.

- By the manufacturing method, it becomes possible to manufacture easily
the gas diffusion layer for fuel cell of the present invention where the void rate of
the gas diffusion layer is changed as will only by adding steps of decomposing,
scattering and removing the hole making agent.

EMBODIMENT OR EXAMPLE

Now the present invention shall be described more in detail referring to examples and comparison examples; however, the present invention is not limited by these examples at all.

(Example 1)

(1) A metal mesh made of SUS316 (line diameter 0.2 mm) is soaked in a FEP dispersion adjusted to the specific weight of 1.09 and thereafter, dried, and heat treated (360 °C, 30 min) to prepare a metal mesh having a FEP layer partially formed on the surface.

(2) Vulcan XC-72 (specific surface area : 250 to 300 m²/g) 7g, PTFE (polytetrafluoro ethylene) powder (PTFE 6CJ) 3g and hole making agent powder (ammonium acid carbonate) 14g are mixed using kerosene as dispersion medium, and excessive kerosene is removed. The obtained mixture is formed into a sheet by rollers.

(3) The sheet mold obtained by the aforementioned (2) and the metal mesh obtained by the aforementioned (1) are stacked, calendered and thereby finished to a thickness substantially equal to the metal mesh thickness, and a sheet shape mold [gas diffusion layer (precursor)] where voids of the metal mesh is filled with the aforementioned mixture is obtained.

(4) Hole making agent powder (ammonium acid carbonate) is decomposed, scattered and removed through the heat treatment of the sheet

shape mold obtained in the aforementioned (3) at 60 °C for 30 min, to prepare a gas diffusion layer (precursor).

(5) Vulcan XC-72 6g, 60 weight 5 of PTFE dispersion 6. 67g are mixed using terpineol as dispersion medium, to prepare a past having an appropriate viscosity.

(6) The paste obtained in the aforementioned (5) is applied to the sheet [gas diffusion layer (precursor)] obtained in the aforementioned (4) to a thickness of the order of 0.05 mm and, thereafter, dried at 60 °C for 30 min, and a second gas diffusion layer (precursor) is stacked on the gas diffusion layer (precursor).

(7) After drying, the gas diffusion layer for fuel cell of the present invention is made by sintering PTFE (water repellent filler) through heat treatment of 360 °C for 30 min.

(Example 2)

(1) A metal mesh made of SUS316 (line diameter 0.2 mm) is soaked in a FEP dispersion adjusted to the specific weight of 1.09 and thereafter, dried, and heat treated (360 °C, 30 min) to prepare a metal mesh having a FEP layer partially formed on the surface.

(2) Ketjenblack (specific surface area : 800 m²/g) 7g, PTFE powder (PTFE 6CJ) 3g and hole making agent powder (ammonium acid carbonate) 14g are mixed using kerosene as dispersion medium, and excessive kerosene is removed. The obtained mixture is formed into a sheet by rollers.

(3) The sheet mold obtained by the aforementioned (2) and the metal mesh obtained by the aforementioned (1) are stacked, calendered and thereby finished to a thickness substantially equal to the metal mesh thickness, and a sheet shape mold [gas diffusion layer (precursor)] where voids of the metal mesh is filled with the aforementioned mixture is obtained.

(4) Hole making agent powder (ammonium acid carbonate) in the sheet shape mold [gas diffusion layer (precursor)] is decomposed, scattered and removed through the heat treatment of the sheet shape mold [gas diffusion layer (precursor)] obtained in the aforementioned (3) at 360 °C for 30 min, after 5 having dried at 60 °C for 30 min, and at the same time, PTFE (water repellent filler) is sintered to prepare a gas diffusion layer.

(5) Vulcan XC-72 6g, 60 weight % of PTFE dispersion 6. 67g are mixed using terpineol as dispersion medium, to prepare a past having an appropriate viscosity.

10 (6) The paste obtained in the aforementioned (5) is applied to the sheet (gas diffusion layer) obtained in the aforementioned (4) to a thickness of the order of 0.02 mm and, thereafter, dried at 60 °C for 30 min, and a second gas diffusion layer (precursor) is stacked.

15 (7) After drying, the gas diffusion layer for fuel cell of the present invention is made by sintering PTFE (water repellent filler) in the second gas diffusion layer (precursor) through a heat treatment of 360 °C for 30 min.

(Comparison Example 1)

(1) A carbon paper TGP-060 (thickness : 0.2 mm) made by TORAY Co., LTD. is soaked in a PTFE dispersion adjusted to a specific weight of 1.10 and 20 thereafter, dried, and heat treated (360 °C, 30 min).

(2) Vulcan XC-72 6g, 60 weight % of PTFE dispersion 6. 67g are mixed using terpineol as dispersion medium, to prepare a past having an appropriate viscosity.

25 (3) The paste obtained in the aforementioned (2) is applied to the sheet obtained in the aforementioned (1) to a thickness of the order of 0.02 mm and, thereafter, dried at 60 °C for 30 min, to make a gas diffusion layer.

(4) After drying, the gas diffusion layer for comparison is formed by

sintering PTFE (water repellent filler) through a heat treatment of 360 °C for 30 min.

[Element Cell for Test]

An element cell for test of 25 cm² in electrode area is prepared for evaluation of respective cells, by making the gas diffusion layer prepared in the Examples 1 and 2 and Comparison Example 1 the air electrode side gas diffusion layer, and using the gas diffusion layer prepared in the Comparison Example 1 as the fuel electrode side gas diffusion layer for all.

[Test Results]

10 Fig. 4 shows the current voltage characteristics of the element cell using the gas diffusion layer of the Examples 1 and 2 and Comparison Example 1. In every element cell prepared by any of Examples, performances substantially equal to the comparison example 1 can be obtained.

15 Fig. 5 shows the air availability dependency of cell voltage in each element cell of the Examples 1 and 2 and Comparison Example 1. In case of Example 2, the voltage tends to lower suddenly at the high air availability side, while the voltage drop amount at the lower air availability side tends to become smaller than that of the conventional example and the Example 1, whereby, performances substantially equal to the comparison example 1 can be obtained.

20 The gas diffusion layer for fuel cell of claim 1 of the present invention being formed of a mesh sheet having an heat resistance and an acid resistance, and a mixture of electrically conductive powder and water repellent filler for filling voids of the mesh sheet, it becomes possible to prepare the gas diffusion layer occupying a large part of the material cost of the element cell of fuel cell at 25 a low cost, as a high strength and cheap material can be used as mesh sheet and, moreover, a production excellent in mass productivity is enabled as it becomes possible to take up the gas diffusion layer (sheet) by using a flexible

material as mesh sheet, and also the mesh sheet plays the role of cell support as it present a high mechanical strength, or other remarkable effects are deployed.

Besides, the gas diffusion layer for fuel cell of claim 1 of the present invention is excellent in gas permeability, water repellency or others, and deploys a remarkable effect of being able to supply the catalyst layer with reaction gas by well diffusing, and at the same time, to discharge reaction produced water and moving water satisfactory.

As the gas diffusion layer for fuel cell of claim 2 is the gas diffusion layer for fuel cell of claim 1, wherein a second gas diffusion layer is stacked on a face of the gas diffusion layer in contact with the catalyst layer, the second gas diffusion layer being formed of the mixture of electrically conductive powder and water repellent filler, and presenting a void rate smaller than that of the gas diffusion layer, it can deploy the same effects as the gas diffusion layer for fuel cell of claim 1 and, furthermore, the second gas diffusion layer allows to form more uniform catalyst layer, and moreover, to control satisfactorily the supply/discharge of reaction produced water and moving water.

The gas diffusion layer for fuel cell of claim 3 is the gas diffusion layer for fuel cell of claim 2, wherein the content of water repellent filler contained in the second gas diffusion layer is formed higher than the content of water repellent filler contained in the gas diffusion layer and has a remarkable effect of allowing to control the evaporation scattering of reaction water and moving water to the reaction gas.

The gas diffusion layer for fuel cell of claim 4 is the diffusion layer for fuel cell of any of claims 1 to 3, wherein the fiber forming the mesh sheet is coated beforehand with water repellent material and, thereby, has remarkable effects of enhancing the water repellency in the vicinity of the fiber of mesh sheet,

improving and keeping the gas permeability, and making the repellent material to act as adherent between the fiber and the electrically conductive powder as carbon powder, thereby preventing the electrically conductive powder as carbon powder from falling from the gas diffusion layer for fuel cell.

5 The gas diffusion layer for fuel cell of claim 5 is the gas diffusion layer for fuel cell of any of claims 2 to 4, wherein the thickness of the second gas diffusion layer is smaller than that of the gas diffusion layer, whereby, the effect of the second gas diffusion layer poor in gas diffusion is reduced, and has a remarkable effect of maintaining the gas diffusion of the whole cell.

10 The gas diffusion layer for fuel cell of claim 6 is the gas diffusion layer for fuel cell of any of claims 2 to 5, wherein the electrically conductive powder used for the gas diffusion layer and the second gas diffusion layer is carbon powder, which is easily available and cheap, and the specific surface area of the carbon powder used for the gas diffusion layer is made smaller than the specific 15 surface area of the carbon powder used for the second gas diffusion layer, thereby, the absorbency of the gas diffusion layer becomes higher than that of the second gas diffusion layer, allowing to have a remarkable effect of allowing to move excessive moisture in the second gas diffusion layer and evaporate in the gas, without stagnation or detention.

20 The manufacturing method of the gas diffusion layer for fuel cell of claim 7 of the present invention has a remarkable effect of allowing to manufacture easily a gas diffusion layer for fuel {{cell}} wherein the void rate of the gas diffusion layer is changed as will, only by adding the step of decomposing, scattering and evaporating the hole making agent.

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